Acoustic Scattering Models of Zooplankton and Microstructure

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LONG-TERM GOALS

To understand the acoustic reverberation properties of zooplankton and microstructure. The results will lead to improved capability in 1) predicting sonar performance and 2) use of sonars in the mapping of the zooplankton and microstructure.

OBJECTIVES

To understand the physics of the scattering by naturally occurring (complex) bodies so that realistic acoustic scattering models of zooplankton and microstructure can be developed.

APPROACH

The research is a balance of theoretical analysis, numerical simulations, and experimentation in the laboratory and local waters at WHOI. The theories are approximate and have included various ray, volume integration, and modal-series-based solutions. An acoustic pulse-echo laboratory is used to collect backscatter data off of the animals and turbulence over a wide range of acoustic frequencies (24 kHz to 1 MHz) and all angles of orientation (0 to 360 degrees in 1-degree steps). A high performance towed platform (BIOMAPER-II) is used to simultaneously collect acoustic backscatter data (transducers at five frequencies (43 kHz to 1 MHz) looking up and down), video data, and environmental data (temperature, etc.).

WORK COMPLETED

A number of major tasks were completed this year involving various parallel efforts of theoretical, data analysis, and field work.

1) PUBLICATIONS. In FY98, six peer-reviewed papers appeared in print and three other papers (for refereed journals) were submitted or remained under consideration for publication. Also, we have continued to synthesize much of our findings from many years of research in this area. The book manuscript that was submitted in the previous year has been accepted and is currently being prepared

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for publication. Three book chapters for another book were revised and resubmitted and seven conference proceedings were submitted. 2) COMPARATIVE ANALYSIS BETWEEN LABORATORY DATA FROM TWO MAJOR CLASSES OF ZOOPLANKTON. Over the past several years, extensive sets of acoustic backscattering data were collected in the laboratory from live shrimp and snails. The data spanned a wide range of frequencies (50 kHz to 1 MHz) and angles of orientation (0 to 360 degrees, in 1-degree increments). The animals were chosen as they broadly resembled commonly occurring planktonic organisms that may dominate the acoustic echoes. In addition, the snails represent an important class of benthic sound scatterer. The high frequency broadband data were analyzed for each animal over ranges of angle of orientation that correspond to the natural behavior of the animals in the ocean. The pulse-compression analysis showed distinct differences in the echo signature between the animals and the ability to infer animal size. 3) ANALYSIS OF IN-SITU MEASUREMENTS OF TARGET STRENGTHS OF GAS-BEARING ZOOPLANKTON. In 1998, a remotely operated vehicle was used to deploy acoustic transducers so that the acoustic scattering by siphonophores, a gas-bearing animal, could be measured at depth in their natural environment. Video images of the animals, co-registered with the acoustic data, were also collected. A "quick-look" analysis of target strengths was performed after the cruise. In this current year, target strengths were extracted from the (single beam) data by two methods, one a least squares fit with a "forward" calculation and the other an inverse method. 4) ACOUSTIC/OPTIC SURVEYS OF A SHALLOW-WATER COASTAL REGION USING BIOMAPER-II. Cruises #2 and #3 of a five-cruise series were completed this year using the newly developed BIOMAPER-II system. This system, which contains five acoustic frequencies (43 kHz to 1 MHz), a video plankton recorder, and various environmental sensors, was used to map the spatial and temporal variability of zooplankton and internal waves over Georges Bank, a shallow water coastal region off of Cape Cod, MA. 5) CONTINUED ANALYSIS OF BIOMAPER-II CRUISE #1 AND DATA PROCESSING AND PRELIMINARY ANALYSIS OF BIOMAPER-II CRUISES #2 AND #3. Major portions of the data from the three cruises have been processed and analyzed (Figure 1). A wide range of species and corresponding anatomical groups were present in the surveys. The diversity is being taken into account by use of the various models developed by us. Environmental data is being processed so that scattering due to turbulence can be taken into account.

RESULTS

SIZING ANIMALS. Analysis of the extensive set of laboratory data from the two types of animals demonstrates that the animals can be sized by use of (broadband) pulse-compression methods. This approach will have great utility in future advanced acoustic systems. SCATTERING BY GAS-BEARING ZOOPLANKTON. To date, there have not been reliable scattering models regarding gas-bearing zooplankton. One main issue was that the size of the gas (which can dominate the echo) is not well known at the deeper depths. These results are the first major step toward development of a model for these animals. They will be used in the current analysis of the BIOMAPER-II data. ACOUSTIC/OPTIC SURVEYS OF ZOOPLANKTON IN A SHALLOW WATER COASTAL REGION. Through the use of our array of acoustic scattering models, we have identified the dominant acoustic scatterers in the different regions. This has allowed us to determine the spatial and temporal variability of the corresponding species.

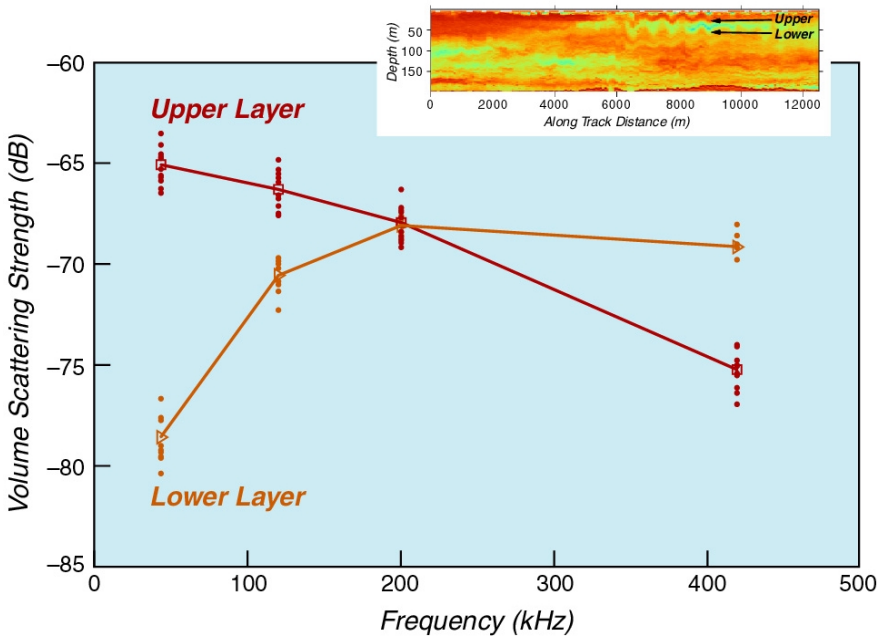

Figure 1. Acoustic backscattering response of two layers in an internal wave, as measured with BIOMAPER-II. The scattering characteristics of the upper and lower layers are consistent with the scattering by turbulence and zooplankton, respectively.

IMPACT/APPLICATIONS

The impact from these results is three-fold: 1) Through development of these models, as motivated by the zooplankton and microstructure applications, we have formulated analytical and experimental approaches for the description of the scattering of sound by bodies with complex shapes and material property compositions. The approaches are applicable to a wide range of body types (beyond the specific cases of zooplankton and microstructure). In addition to the successful application to zooplankton and microstructure they have, for example, been successfully applied to irregular metallic structures. 2) The development of these scattering models has improved the accuracy of interpretation of acoustic surveys of zooplankton and microstructure as discussed in the papers recently published by us and being submitted by others. 3) The research involving the benthic shelled animals can help make predictions of acoustic scattering by shell-covered seafloors more accurate.

TRANSITIONS

1) The British Antarctic Survey has been using one of our models in their interpretation of acoustic surveys of Antarctic krill. 2) The Southampton Oceanography Centre has been using several of our models in their interpretation of acoustic surveys in the N.W. Indian Ocean. 3) Some of our acoustic scattering models have already been used by NUWC/Newport for performance predictions of one of their high frequency acoustics systems. 4) In addition, we have identified two types of zooplankton (siphonophores and pteropods) that have high enough target strengths and occur in sufficiently high numbers that they could interfere with the performance of certain high frequency acoustics systems. By use of our zooplankton scattering models, we have already provided a plausible explanation for some anomalous ("false target") returns in MK48 ADCAP torpedo reverberation data collected by NUWC/Newport that could not be explained by predictions of scattering by the seafloor or sea surface.

5) We have recently conducted high frequency acoustic and video surveys of the Gulf of Maine and observed high concentrations of the gas-bearing animals. The current analysis is giving us information on the target strengths of these animals *at depth* which will help simulation personnel in the Navy make better predictions of sonar performance.

RELATED PROJECTS

1) We have applied experimental methods and scattering models developed as well as equipment purchased under this grant toward at-sea laboratory experiments funded by NSF grant OCE-9201264.
2) We have applied some of the scattering models developed under this grant to help in interpreting acoustic survey data collected over the Georges Bank (a shallow water coastal region). The data were collected under NOAA grant NA16RC0515 as part of the US GLOBEC program.

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